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ABSTRACT

Two Goddard Space Flight Center laser tracking stations were collocated for a short time towards the end of 1971 for the purposes of comparing their tracking performance and quality. The lasers, only 25 meters apart, obtained simultaneous tracking data on eighteen passes of the Beacon Explorer C spacecraft. These data have now been used to determine the location of one laser with respect to the other with the result that the computed position of the second laser agrees with the surveyed position to 4 centimeters in latitude and height, and 1 centimeter in longitude.

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AN EXPERIMENT TO DETERMINE THE RELATIVE POSITIONS OF TWO COLLOCATED LASER TRACKING STATIONS

INTRODUCTION

During October and November 1971 two Goddard Space Flight Center laser tracking systems were collocated at the Goddard Optical Site for the purposes of comparing their satellite ranging capability, in both accuracy and stability. The two tracking systems that were being compared were the fixed experimental laser system (GODLAS) and the mobile laser system (MOBLAS), and they were positioned about 25 meters apart. The method of the experiment was to simultaneously track a satellite from both sites on a number of occasions and, allowing for their difference in position, compare the ranges to the satellite from the two sites. The satellite used for this experiment was the Beacon Explorer C satellite in a 41 degree inclination, near-circular orbit at about 1000 km altitude. This comparison experiment was conducted by the Laser Data Systems Branch of the Advanced Data Systems Division. In summary, the results of this experiment were (ref. 1) that, at that time each system showed noise fluctuations in the individual range measurements to the satellite with an rms of about 50 cm and that from pass to pass, range differences (biases) between the two systems of the same order were observed. These results were exactly what had been expected and completely within the performance specifications of the two systems. Of considerable interest, however, was the result that the average bias between the two systems over the experimental period was only a few centimeters, a result that had been anticipated but not demonstrated until then.

The data that were collected in this experiment are summarized in Table 1. All the passes were on the Beacon Explorer C spacecraft; and Table 1 shows the number of range measurements obtained by each system and the root mean square (rms) of the residuals to the range about adjusted least squares orbital arcs. It is evident from Table 1 that relatively few observations were used on each of the passes during this experiment when compared to the numbers obtained during other experiments, such as the Preliminary Polar Motion Experiment of 1970 (ref. 2), when an average of about 250 points per pass were obtained by each system. This was due to a data sampling procedure adopted for the collocation experiment, which only selected measurements from each station that were nearly simultaneous.

The data coverage is demonstrated in Figure 1, an azimuth and elevation plot. This figure shows that observations to the satellite were obtained in nearly all directions and at many elevations but that the coverage is far from uniformly distributed or abundant. In particular, because the orbital inclination of BE-C

Table 1

Summary of Range Measurements

Date	Time Hrs:Mins	Range Measurements Number		Range RMS cm.	
		GODLAS	MOBLAS	GODLAS	MOBLAS
Nov. 5	22:37	60	78	38	49
8	18:41	35	35	39	47
8	20:34	49	58	53	40
8	22:28	62	105	46	37
9	17:59	26	15	61	33
9	21:48	62	71	54	34
16	15:10	16	26	55	31
16	17:01	69	85	49	52
17	18:14	34	39	56	42
18	15:38	65	26	42	61
18	17:35	49	48	42	76
18	19:28	35	59	34	44
23	16:03	12	18	42	41
30	11:13	9	14	116	40
Dec. 1	8:37	11	25	106	34
1	10:32	16	16	77	27
16	6:04	29	14	76	38
16	7:51	202	242	57	51
Total		841	974		

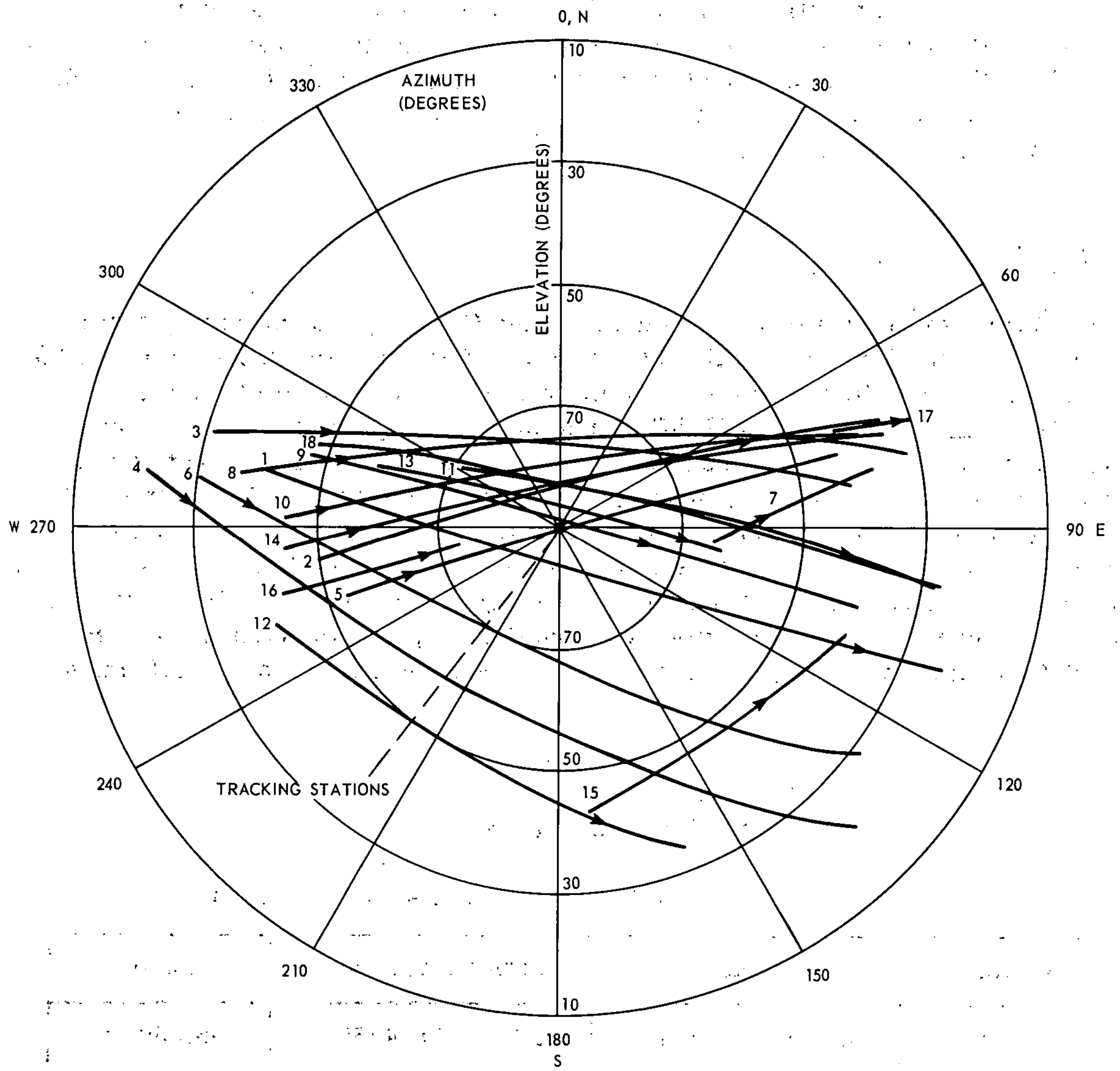

Figure 1. Azimuth vs Elevation for the 18 Passes Tracked

is only 2 degrees larger than the latitude of the tracking stations, all the observations in the northerly direction (azimuth zero degrees) are at elevations of 75 degrees or higher. At such high elevations the contribution of the difference in latitudes of the two stations to the differences in range to the satellite is rather weak. Further, the coverage to the south of the stations is much stronger although it is still not strong. Conversely, the coverage to the east and west of the stations is much more evenly distributed. Thus biases between the two laser ranging systems will tend to cancel for the east-west direction but not for the north-south direction. On this basis we should expect a stronger determination of the relative positions of the two stations in longitude rather than latitude, and it will be seen that this appears to be the case.

METHOD AND RESULTS

The locations of the two tracking stations at the GSFC Optical Site are given in Table 2, together with the relative positions of MOBLAS with respect to GODLAS. Because of their difference in position the ranges to the satellite (at the same time) from the two systems will differ in a known and systematic way. In addition, the effects of range noise and relative bias will be included. What has been attempted in the present experiment is to re-determine the location of one of the tracking systems from the observed range differences and from a knowledge of the way tracking station position errors manifest themselves in the measurements. Figure 2 demonstrates that if the observed range from Station B differs from the expected range for a given location by a quantity, δ_ρ, then the data tries to adjust the station position. This procedure can effectively be carried out at all times

Table 2

Location of Laser Stations

Ground Survey, Datum SAO C-5 (Ref. 4)

Station	Latitude	Longitude, East	Height
GODLAS	39°01' 13."6454	283.10' 18."4456	-6.859 m
MOBLAS	39°01' 14."4668	283°10' 18."4515	-6.879 m

Location of MOBLAS Relative to GODLAS (meters)

25.330 N	0.142 E	-0.020

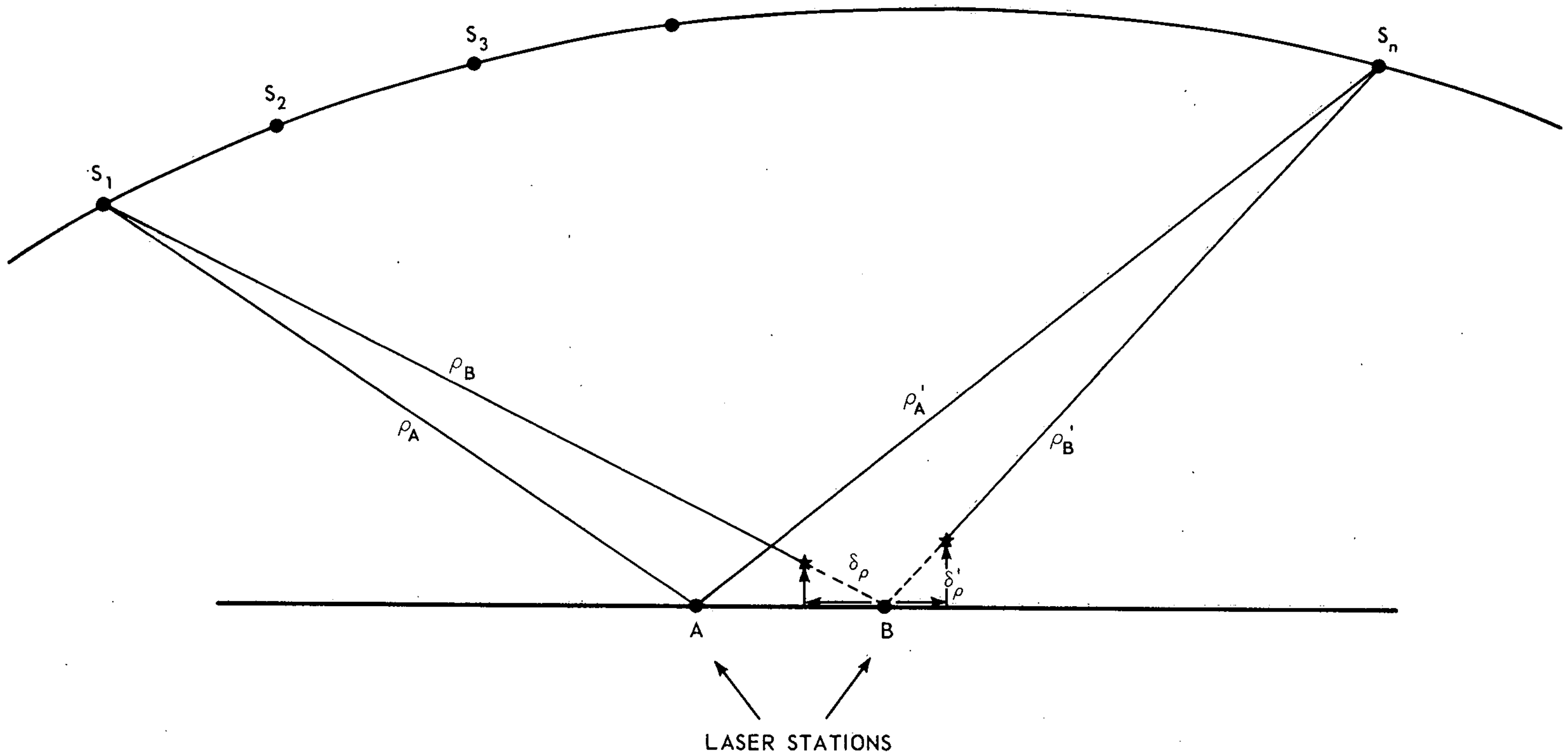

Figure 2. Effect of Range Error on Station Position

of simultaneous measurement from the two stations from which it is evident that for a reasonable number of measurements the range noise is unimportant and only the range biases contribute to the errors. Also, from Figure 2, it is clear that constant biases between two measurements in opposite quadrants tend to cancel out in the horizontal plane but reinforce each other in the vertical direction. Thus, accuracy of the height determinations is probably a measure of the average bias between the two systems.

The method of the determination is therefore to use many passes of the kind shown in Figure 2 to recover the "best" position of the second tracking system. The computer program GEODYN (ref. 3) that was used in this work is a high precision orbit determination program that has the capability of determining tracking station positions and large size geopotential fields. The computational method of GEODYN to recover the coordinates of the second tracking station is to initially determine orbits for each of the short arcs (5 - 10 minutes of time) using the data from both sites at their nominal positions and then to minimize the residuals to the observations on all the arcs simultaneously by adjusting the coordinates of the second station. This procedure eliminates the need for real simultaneity of observations from the two lasers. In principle, all that is required are sufficient observations on each pass from each station to independently determine an orbit.

Although this experiment was conducted with measurements on only one satellite, there is no reason why any number of passes on any number of satellites could not be used. The only parameters common to all the orbital arcs (about 5 to 10 minutes in time) are the coordinates of the two stations. In addition to using the range measurements to the satellite, the directions (azimuth and elevation) obtained by the Mobile laser were also used in the solution. Range measurements alone on a very short orbital arc of a few minutes (from effectively one station) do not have sufficient strength to uniquely determine the path of the satellite, thus the angles were introduced to provide an additional constraint. In the solution, the range measurements were weighted with a one meter rms range noise on each pass and the angle measurements weighted with an rms noise value of 100 arcseconds.

An alternative to introducing the angles could have been the assigning of very large weights to an a priori orbit for each short pass determined from a longer data span. The range measurements would then be unable to change the orbit in the differential orbit improvement part of the computations and thereby to effectively cause the adjustment of the position of the second station to be based on the residuals to the a priori orbit. The disadvantage of this approach is that errors in the a priori orbit propagate directly into the station position adjustment. This disadvantage has to be weighed against the possibility of the biases

in the angles causing errors in the adjusted location of the station in the method that has been used here. In the present experiment, however, it is unlikely that either error source would be significant because of the smallness of the baseline compared to the spacecraft altitude.

Three solutions for the experiment were obtained. The first solution was obtained with the initial position of MOBLAS being given the same coordinates as GODLAS and subsequently being allowed to move according to the minimization of the range residuals. The second solution was obtained with MOBLAS being given an initial position 1 arcsecond in latitude and longitude and 30 meters in height away from its correct position and subsequently being allowed to adjust. The results of these first two solutions were exactly the same and demonstrated the independence of the final result from the nominal position of MOBLAS. The third solution was obtained with the range data from MOBLAS altered by the addition of a 1 meter bias to every range measurement. The purpose of this solution was to assess the sensitivity of the result to bias errors. All three solutions are shown in Table 3.

Table 3 shows that the MOBLAS station adjusts to within approximately 4 cm in latitude and height and 1 cm in longitude of the survey position. It is of significance that the longitude is the most accurately recovered parameter and reflects the well distributed geometry described earlier and shown in Figure 1. The third solution demonstrates how insensitive the longitude is to large biases which is, again, a reflection of the good geometry. The latitude is not recovered as well and is probably due to the lack of low elevation measurements in the northerly direction. The height, however, absorbs the range bias completely and even magnifies it slightly, thus implying that the original good recovery of the height was an indication that the average bias between the systems was probably only a few centimeters. The same conclusion was drawn from the original collocation experiment.

CONCLUSIONS

The data collected during a collocation experiment in 1971 has been re-analyzed to determine if these same data can be used to locate the relative position of one laser with respect to the other. It has been shown that this is possible to an accuracy of a few centimeters and that this is, in part, probably due to the average bias between the lasers being very small, that is, a few centimeters.

The significance of the present result lies not in its application to measuring short distances of a few tens of meters or even kilometers to an accuracy of a few centimeters but rather that it be a necessary accomplishment on the way to

Table 3

Results

	SOLUTION 1		
Initial Position of MOBLAS (at GODLAS)	39°01′ 13″.6454 N	283°10′ 18″.4456 E	-6.859 meters
Recovered Position	39°01′ 14″.4680 N	283°10′ 18″.4511 E	-6.923 meters
Comparison with Survey	0″.0012 (3.70 cm)	-0.0004 (-0.96 cm)	-0.044 meters
	SOLUTION 2		
Initial Position of MOBLAS	39°01′ 15″.4668 N	283°10′ 19″.4515E	+23.121 meters
Recovered Position	Identical to Solution 1		
	SOLUTION 3 (1 Meter Bias Added to Each MOBLAS Measurement)		
Initial Position of MOBLAS	Same as Solution 2		
Recovered Position	39°01′ 14″.4608 N	283°10′ 18″.4535	-5.706 meters
Comparison with Survey	-0″.0060 (-18.5 cm)	0″.0020 (4.8 cm)	1.173 meters

determining the positions of points hundreds or even thousands of kilometers apart. In particular, the experiment has demonstrated that the laser tracking systems themselves are capable of providing the necessary measurements of necessary quality for a limited "geodetic" experiment.

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